

# The Unilateral Isometric Squat: Test Reliability, Inter-limb Asymmetries, and Relationships with Limb Dominance

## ABSTRACT

The aim of the present study was to determine test reliability, establish inter-limb asymmetries and their associations with force production capability on the dominant (D) and non-dominant (ND) limbs during the unilateral isometric squat test. Twenty-eight recreational sport athletes attended a single test session after familiarization and performed three trials on each limb with 140° of hip and knee flexion, to assess peak force (PF), rate of force development (RFD) and impulse at different time intervals. Reliability, inter-limb asymmetries and Pearson's  $r$  correlations were computed thereafter. Test reliability was metric-dependent with only PF showing good levels of reliability on both limbs (CV = 5.44-5.70; ICC = 0.93-0.94). Inter-limb asymmetries ranged from 8.36-25.46%, with a tendency for RFD and impulse asymmetries to reduce as time intervals increased. Three significant negative relationships out of a possible 49 ( $r = -0.43$  to  $-0.47$ ;  $p < 0.05$ ) were found between asymmetries and performance on the D limb. However, 31 significant negative correlations ( $r = -0.42$  to  $-0.71$ ;  $p < 0.05$ ) were found between asymmetries and performance on the ND limb. These findings demonstrate that practitioners may only be able to use PF as a reliable test metric during a unilateral isometric strength test. Furthermore, the negative association between asymmetries and strength performance on the ND limb may indicate that the reduction of imbalances through targeted training interventions may be warranted.

**Key Words:** Strength assessment; side-to-side differences; peak force

## INTRODUCTION

Numerous methods exist when assessing an athlete's strength capabilities such as isokinetic dynamometry to measure torque (12,33), one-repetition maximum (1RM) testing during the back squat exercise (16,34), and isometric tests assessing maximal force production via the isometric mid-thigh pull (IMTP) or squat (9,14,18). Isokinetic dynamometry may offer useful insight into inter- and intra-limb differences for the quadriceps and hamstring muscles at different contraction velocities. However, such methods are typically confined to a laboratory setting; thus, may not always be viable for practitioners in a team-sport environment (7). The back squat is a commonly programmed exercise during strength programs and often suggested as a means of assessing lower body strength (16,21,34). While the importance of this exercise is not being disputed, it has been suggested that high levels of mobility are required for optimal technique, which becomes especially important if using maximal loads (7). In addition, assuming that optimal technique can be adhered to for this exercise, 1RM protocols (which are often suggested) can be time-consuming, potentially reducing their usability with large groups of athletes (26). With recent literature highlighting strength as a critical physical quality to develop for both performance (36,37) and injury risk reduction (24), alternative methods of strength assessment may need to be considered.

The IMTP or isometric squat offer practitioners with a useful indication of an athletes' force production capabilities and has been suggested to be more time-efficient than isokinetic dynamometry and 1RM back squat testing (7). Further to this, isometric strength testing permits the generation of force-time curves, which enables practitioners to examine rapid force production characteristics over specific time intervals (13,18,38). In turn, this may provide practitioners with some insight into athletes' force production capacity during athletic tasks underpinned by strength such as sprinting, jumping and changing direction (39). Previous investigations have compared these two tests and reported acceptable reliability for peak force

([PF]:  $ICC \geq 0.86$ ,  $CV \leq 9.4\%$ ) (9). Results of this study highlighted significantly greater peak force values for the isometric squat; thus, it was suggested that if practitioners wish to establish athletes' true lower body maximal force production capabilities, the isometric squat might be the preferred choice. However, this was conducted during bilateral testing and the literature pertaining to a unilateral version of this test is limited (18,19).

Spiteri et al. (35) investigated the effect of strength (using the unilateral isometric squat test) on foot kinetics and kinematics during a change of direction speed (CODS) task. Results showed that greater lower body force production capabilities were associated with greater magnitude plant foot kinetics, and thus, faster CODS performance. In addition, although not the primary focus of their study, both limbs reported strong reliability for PF ( $ICC = 0.97$ ;  $CV = 5.5-7.0\%$ ). However, this was the only metric to report reliability statistics. Hart et al. (18) assessed the reliability of PF and rate of force development (RFD) during the unilateral isometric squat on dominant (D) and non-dominant (ND) limbs and reported acceptable reliability ( $ICC \geq 0.83$ ) for both measures with the exception of RFD on the ND limb ( $ICC = 0.36$ ). This test was also used to establish inter-limb strength asymmetries in 31 Australian rules football athletes (19), where players were required to kick a ball to a target 20 m away. For the purpose of data analysis, the sample was divided into accurate ( $n = 15$ ) and inaccurate ( $n = 16$ ) kickers, and showed that the accurate group were almost perfectly symmetrical (1% asymmetry). In contrast, the inaccurate group showed an 8% asymmetry with the non-kicking limb (required to stabilise during the action of kicking) demonstrating weaker PF values. With limited literature on the unilateral isometric squat to date, further research is warranted to establish its ability to detect inter-limb asymmetries and its associations with strength capacity (i.e., do larger asymmetry scores relate to reduced force production on a given limb), given previous literature has highlighted that strength imbalances may be detrimental to physical and sporting performance (5).

Therefore, the aims of the present study were threefold: 1) establish the reliability of the unilateral isometric squat for multiple metrics when tested on a force platform, 2) quantify inter-limb asymmetries for these associated metrics and, 3) establish the relationship between inter-limb asymmetries and force-time characteristics for each limb. It was hypothesized that significant negative relationships would exist between asymmetries and isometric squat performance.

## **METHODS**

### **Experimental Approach to the Problem**

A familiarization session provided subjects with the opportunity to practice test procedures as many times as required after all relevant test instructions had been given; thus, reducing any potential learning effects from the exercise. One week later, subjects attended a single test session and performed three trials of the unilateral isometric squat on each limb. This test was chosen for two reasons: 1) recent research has shown that the isometric squat may be better at depicting isometric force production than the isometric IMTP, albeit bilaterally (9) and, 2) recent research has investigated the unilateral IMTP (14,38); thus, it was decided that comparable research was needed on the isometric squat test. Procedures were conducted on a single force platform (PASPORT force plate, PASCO Scientific, California, USA) sampling at 1000 Hz. A standardised dynamic warm up consisting of dynamic stretches to the lower body (multi-planar lunges, inchworms, ‘world’s greatest stretch’) was conducted before data collection, followed by three practice trials on each limb at approximately 60, 80, and 100% perceived effort for the isometric squat test. Three minutes of rest was provided after the final warm up trial and the first data collection trial.

## Subjects

Twenty-eight male recreational sport athletes with a background in soccer and rugby (age =  $27.29 \pm 4.6$  years; mass =  $80.72 \pm 9.26$  kg; height =  $1.81 \pm 0.06$  m) volunteered to take part in this study. A minimum of 27 participants was determined from a priori power analysis using G\*Power (Version 3.1, University of Dusseldorf, Germany) implementing statistical power of 0.8 and a type 1 alpha level of 0.05 which has been used in comparable literature (13). Inclusion criteria required all subjects to have a minimum of one year's resistance training experience, with any subject excluded from the study if they had any lower body injury at the time of testing. Subjects were required to complete informed consent forms to demonstrate that they were willing and able to undertake all testing protocols. Ethical approval was granted from the London Sport Institute research and ethics committee at Middlesex University.

## Procedures

### *Unilateral Isometric Squat Test.*

A custom built 'ISO rig' (Absolute Performance, Cardiff, UK) was used for this test protocol (Figure 1). A goniometer was used to measure approximately  $140^\circ$  of hip and knee flexion for each participant (7,18), with full extension of the knee joint equalling  $180^\circ$ . To determine knee angle, the fulcrum of the goniometer was positioned on the lateral epicondyle of the femur. The stabilization arm was lined up along the line of the fibula (in the direction of the lateral malleolus) and the movement arm was lined up with the femur (pointing towards the greater trochanter at the hip). To determine hip angle, the fulcrum of the goniometer was positioned on the greater trochanter of the femur. The stabilization arm was lined up along the line of the femur (in the direction of the knee joint) and the movement arm was lined up along the line of the torso (pointing towards the shoulder joint). The non-stance limb was required to hover next

to the working limb, so as to try and keep the hips level during the isometric squat action; thus, aiding balance and stability.

To determine bodyweight, subjects were required to remain motionless on the force plate for two seconds. Once in position, each trial was then initiated by a “3, 2, 1, Go” countdown and subjects were instructed to try and extend their knees and hips by driving up as “fast and hard as possible” against the bar for five seconds (14). The force plate was subsequently ‘zeroed’ after each trial before subjects stepped on to the force plate for subsequent trials. Recorded metrics included PF, RFD from 0-0.1s, 0.1-0.2s, 0.2-0.3s and impulse from 0-0.1s, 0.1-0.2s and 0.2-0.3s. The first meaningful change in force was established when values surpassed five standard deviations (SD) of each subject’s body weight (14,31). PF was defined as the maximum force generated during the test. RFD was defined as the rate of change in force (epoch) after the first meaningful onset was recorded at the start of each specified time point (30); while impulse was defined as the net force multiplied by the time taken to produce it at each specified time point; i.e., the area under the force-time curve (14). Limb dominance was defined as the limb with the greatest score between the two and subsequently used in this way for the calculation of inter-limb asymmetries. Each participant conducted testing on their left leg first and then alternated between limbs until three trials were conducted for each limb. The trial with the greatest PF was used for subsequent analysis to ensure that RFD and impulse time integrals were being analyzed from the same trial.

\*\*\* INSERT FIGURES 1a & 1b ABOUT HERE \*\*\*

## Statistical Analyses

Initially, all force-time data were saved as text files and analysed unfiltered (13) in a custom-built spreadsheet in Microsoft Excel™ in line with recent suggestions from Chavda et al. (11). All data were expressed as means and standard deviations (SD), and later transferred into SPSS (V.24, Chicago, IL, USA) for additional analyses. Reliability was quantified for each metric using the coefficient of variation (CV) and intraclass correlation coefficient (ICC). However, given that it is highly plausible that one of these methods may report strong reliability while the other shows unacceptable variability, results were interpreted in line with previous suggestions from Bradshaw et al. (8). When considered together, average reliability was considered ‘good’ if  $ICC > 0.67$  and  $CV < 10\%$ , ‘moderate’ if  $ICC < 0.67$  or  $CV > 10\%$ , or ‘poor’ if  $ICC < 0.67$  and  $CV > 10\%$  (8). Inter-limb asymmetries were quantified as the percentage difference between limbs using the formula proposed by Bishop et al. (3,4):  $(100/(\text{maximum value}) * (\text{minimum value}) - 1 + 100)$ . Given that the desired goal for all metrics in the present study was to demonstrate the highest value possible, the authors suggest that this equation (which uses the maximum value as a reference value) is a valid means of quantifying inter-limb differences for unilateral tests (3). Pearsons  $r$  correlations were conducted to determine the relationships between the asymmetry score and test scores for D and ND limbs respectively. Statistical significance for these relationships were set at  $p < 0.05$ . Finally, the magnitude of change was quantified between limbs using Cohen’s  $d$  effect sizes:  $(\text{Mean}_D - \text{Mean}_{ND}) / \text{SD}_{\text{Pooled}}$ . These were interpreted in line with a suggested scale by Hopkins et al. (22) where  $< 0.2$  = trivial;  $0.2-0.6$  = small;  $0.6-1.2$  = moderate;  $1.2-2.0$  = large;  $2.0-4.0$  = very large; and  $> 4.0$  = near perfect.

## RESULTS

Mean scores, effect sizes and test reliability data are presented in Table 1. The majority of metrics demonstrated moderate reliability, with the exception of PF on both limbs and RFD on the ND limb (0.2-0.3s) which showed good reliability, and impulse on the ND limb (0-0.1s) which showed poor reliability. When determining magnitude of change between limbs, effect sizes were small (0.32 to 0.56) for all metrics. For asymmetry (Figure 2), the smallest differences were seen for PF (8.36%) and a noticeable trend was evident for these inter-limb differences when RFD and impulse were viewed. Asymmetries were largest during the first timeframe (0-0.1s) and continued to decrease from 0.1-0.2 and 0.2-0.3s respectively. Finally, relationships between asymmetry scores and limb dominance are presented in Table 2. Of note, all significant relationships ( $p < 0.05$ ) were negative indicating that larger asymmetries were indicative of reduced force outputs. Three significant negative relationships were shown with the D limb ( $r$  range = -0.43 to -0.47), whilst 31 negative correlations (out of a possible 49) were reported with the ND limb ( $r$  range = -0.42 to -0.71).

\*\*\* INSERT TABLE 1 ABOUT HERE \*\*\*

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## DISCUSSION

The aims of the present study were to establish the reliability of the unilateral isometric squat across a range of metrics and quantify their associated inter-limb asymmetries. A further aim was to establish the relationships between the asymmetry scores and performance on the D and



ND limbs. The majority of metrics reported moderate reliability, with the exception of PF and RFD on the ND limb (0.2-0.3s) which was good and impulse from 0-0.1s which was poor on the ND limb. Inter-limb asymmetries varied across metrics highlighting their task-specific nature and relationships between asymmetry scores and limb dominance highlighted multiple negative associations; the majority of which were with the ND limb.

Table 1 shows the reliability of metrics during the unilateral isometric squat test. The only metric to report good reliability on both limbs was PF which is in line with previous research (18,35), suggesting that this is a reliable metric during this unilateral test. To the authors' knowledge, only two studies have reported reliability data on the unilateral isometric squat test. Spiteri et al. (35) reported near perfect relative reliability ( $ICC = 0.97$ ) and acceptable variability ( $CV = 5.5-7.0\%$ ) for PF. No other metrics were investigated due to the aims being associated with investigating the effects of strength on kinetics and kinematics of a CODS task. Hart et al. (18) showed that RFD from 0-0.3s was only reliable on the D limb, with the ND limb reporting ICC of 0.36 and CV of 46%. In contrast, the present study showed good reliability on the ND limb for RFD between 0.2-0.3s and moderate reliability between 0-0.1 and 0.1-0.2s time points (which Hart et al. (18) did not report). It is worth noting though that Hart et al. (18) used a portable device when investigating test reliability, which allowed some aspect of 'sway' and therefore, instability. In the present study, the platform for testing was stable (Figure 1), which may have contributed to the improved reliability data on the ND limb. In addition, RFD was calculated differently in the present study compared to Hart et al. (18), which may have also contributed to different reliability statistics. Impulse showed a similar trend in results with each time point showing moderate reliability with the exception of the ND limb between 0-0.1s (which was poor). In addition, although RFD and impulse showed moderate reliability at the earlier time intervals, CV values were noticeably higher than 10% indicating that practitioners should be cautious when using these metrics at those time points.

As such, if practitioners want to quantify data from the unilateral isometric squat, PF may be the only truly reliable metric to use if the current time intervals are employed for RFD and impulse analysis.

However, given the paucity of reliability data for the unilateral isometric squat, it is worth highlighting that comparable results have been reported for the unilateral IMTP (38). Dos'Santos et al. (14) reported better within-session reliability data than the present study, but used different time intervals in the analysis. Impulse was analyzed from 0-0.1s (ICC = 0.83-0.87; CV = 9.3-9.5%), 0-0.2s (ICC = 0.82-0.86; CV = 10.3-10.8%) and 0-0.3s (ICC = 0.82-0.88; CV = 10.5-11.6%), noting here that a range is provided because separate data exists for each limb. However, PF was comparable to the present study with ICC of 0.94 on both limbs and CV values of 4.7-5.0%. Similarly, Thomas et al. (38) reported between-session reliability data for the unilateral IMTP. Again, comparable data was reported for PF (ICC = 0.95-0.97; CV = 4.15-4.91%), and the same time intervals as used by Dos'Santos et al. (14) were used to analyze impulse. Between-session reliability data for impulse at 0-0.1s (ICC = 0.88-0.94; CV = 7.08-8.30%), 0-0.2s (ICC = 0.85-0.95; CV = 6.16-9.24%) and 0-0.3s (ICC = 0.92-0.95; CV = 6.27-7.43%) again showed notably better findings than the present study. Thus, it is plausible that the reliability data for impulse in the present study would have been improved if analyzed in line with the methods of Dos'Santos et al. (14) and Thomas et al. (38) and that consecutive 0.1s time intervals are not suitable, which has been previously suggested (27). However, further research is warranted to compare the two methods of analysis during unilateral isometric strength testing.

Figure 2 shows the inter-limb asymmetry scores for each metric. Previous research has highlighted how task-specific asymmetries can be (4,20,24,28,31); however, this concept can now also be applied to different metrics within the same test. Figure 2 clearly shows substantially different asymmetries for PF, RFD, and impulse metrics, in addition to large

standard deviations (as represented by the error bars). The PF asymmetry values are in agreement with those reported by Hart et al. (19) who used the same test to determine PF asymmetries (also 8%) in Australian rules football athletes. Where RFD and impulse are concerned, there was a noticeable trend for asymmetries to reduce as time increased; however, the concept of test variability must also be considered. Previous research has highlighted that asymmetries may not be 'real' unless they are greater than the CV value (2,3,15). Therefore, despite the large asymmetry values seen for RFD between 0-0.1s and impulse between 0-0.1 and 0.1-0.2s, the accompanying CV values at these time points were larger (Table 1). Thus, with the test variability score (CV) being greater than the inter-limb difference, practitioners should be mindful about using such data as part of an athlete profiling report. With that in mind, meaningful asymmetry scores are evident for PF, RFD between 0-0.1 and 0.1-0.2s, and impulse between 0.2-0.3s. Furthermore, with previous research highlighting that PF asymmetries of 8% can have a detrimental effect on sporting performance (19), and 10% being a possible threshold for heightened injury risk in quadriceps strength (23), the present values of 8.36-15.45% could be a strong consideration for practitioners when planning subsequent training interventions.

Table 2 shows the correlations between all asymmetry scores and the performance on D and ND limbs for each metric. The first point to consider is that regardless of statistical significance, nearly all correlations are negative, suggesting that the larger an asymmetry is, the less force or RFD occurs. For the D limb, 3 out of 49 individual correlations were significant, suggesting that asymmetries do not affect the performance on the D limb for the most part. Given only three metrics showed significance on the D limb, these findings can likely be considered random anomalies. However, the ND limb showed 31 out of 49 negative correlations, suggesting that being asymmetrical is detrimental to the strength performance on the ND limb. Noting that many sporting actions occur unilaterally (such as sprinting and changing direction), and that many of these are underpinned by strength (39), it seems logical to suggest that the

correction of these imbalances and strengthening for the ND limb could be advantageous. Furthermore, a recent critical review of the effects of asymmetry on athletic performance highlighted that the reduction of imbalances could be seen from a ‘windows of opportunity’ perspective (28). In essence, with additional focus being provided to the weaker limb, this may assist in reducing any existing side-to-side differences and enhance overall force output bilaterally. Given the volume of negative relationships reported on the ND limb in the present study, this may be a viable option for practitioners to consider if similar results are found with their athletes. Previous research has suggested that unilateral training is most likely a favourable method for reducing inter-limb asymmetries (6,10,17). In this context, it may be suggested that exercises such as split squats, step ups, and lunges might be appropriate for reducing strength imbalances; thus, improving the performance of the ND limb in a task such as the unilateral isometric squat.

This study was not without some limitations. Firstly, it only investigated within-session reliability data; thus, further research should aim to establish between-session reliability data for the chosen metrics. This between-session analysis should also be computed for asymmetry data as well, noting that we alluded to the task-specific nature of asymmetry earlier. In addition, these findings can only be attributed to recreational sport athletes. Given the importance of strength for athletic development (36,37), future research should also aim to establish reliability data in elite athlete populations for unilateral isometric tasks.

In summary, PF may be the only truly reliable metric when analyzing force-time curves from the unilateral isometric squat test. With real inter-limb asymmetries of 8.36-15.45% and multiple relationships with reduced force characteristics on the ND limb, it is suggested that the reduction of between-limb differences in strength may be warranted.

## **PRACTICAL APPLICATIONS**

The findings of the present study show that if practitioners wish to use the unilateral isometric squat to assess force production capabilities of each limb, PF may be the only metric to interpret with real confidence given its strong reliability. Asymmetries in strength as small as 6.6% have been shown to correlate with reduced jump performance (1), therefore the inter-limb differences reported in the present study can be considered quite large. When their effects on the force production capability of the ND limb are considered as well, the results indicate that practitioners should be mindful of such large imbalances and it seems logical to suggest that practitioners may wish to consider reducing these imbalances. If said imbalances are viewed as ‘windows of opportunity’, the addition of unilateral strength exercises such as split squats, lunges and step ups in conjunction with bilateral lifts, may help to reduce asymmetries. The relevance here being that many sporting actions occur unilaterally for team sport athletes (such as sprinting and changing direction), many of which are underpinned by strength. Thus, the reduction of strength asymmetries seems like a logical suggestion for athlete populations.

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## The Unilateral Isometric Squat



Figures 1a and 1b: Example positioning during the unilateral isometric squat test.

Table 1: Mean  $\pm$  standard deviation, effect size (between D and ND limbs) and reliability data for the unilateral isometric squat test. Peak force measured in Newtons, RFD measured in Newtons per second, and impulse measured in Newton seconds.

| Test Variable         | Mean $\pm$ SD         | Effect Size | CV (%) | ICC (95% CI)     | Reliability Descriptor |
|-----------------------|-----------------------|-------------|--------|------------------|------------------------|
| Peak force (D)        | 1661.80 $\pm$ 408.67  | 0.32        | 5.70   | 0.93 (0.87-0.96) | Good                   |
| Peak force (ND)       | 1530.35 $\pm$ 417.79  |             | 5.44   | 0.94 (0.88-0.97) | Good                   |
| RFD 0-0.1s (D)        | 5676.94 $\pm$ 2503.34 | 0.48        | 18.57  | 0.87 (0.77-0.93) | Moderate               |
| RFD 0-0.1s (ND)       | 4458.20 $\pm$ 2565.73 |             | 25.98  | 0.78 (0.64-0.88) | Moderate               |
| RFD 0.1-0.2s (D)      | 4625.61 $\pm$ 1651.47 | 0.36        | 12.37  | 0.92 (0.86-0.96) | Moderate               |
| RFD 0.1-0.2s (ND)     | 4023.74 $\pm$ 1652.79 |             | 13.10  | 0.92 (0.85-0.96) | Moderate               |
| RFD 0.2-0.3s (D)      | 3615.60 $\pm$ 1137.48 | 0.32        | 10.37  | 0.89 (0.81-0.94) | Moderate               |
| RFD 0.2-0.3s (ND)     | 3251.05 $\pm$ 1135.98 |             | 9.20   | 0.91 (0.85-0.96) | Good                   |
| Impulse 0-0.1s (D)    | 31.46 $\pm$ 12.48     | 0.56        | 23.48  | 0.77 (0.61-0.87) | Moderate               |
| Impulse 0-0.1s (ND)   | 24.21 $\pm$ 13.18     |             | 32.12  | 0.60 (0.39-0.77) | Poor                   |
| Impulse 0.1-0.2s (D)  | 109.68 $\pm$ 42.13    | 0.47        | 14.59  | 0.90 (0.82-0.95) | Moderate               |
| Impulse 0.1-0.2s (ND) | 89.21 $\pm$ 44.04     |             | 20.26  | 0.83 (0.70-0.91) | Moderate               |
| Impulse 0.2-0.3s (D)  | 211.50 $\pm$ 72.72    | 0.42        | 12.14  | 0.92 (0.85-0.96) | Moderate               |
| Impulse 0.2-0.3s (ND) | 180.96 $\pm$ 73.39    |             | 13.71  | 0.89 (0.80-0.94) | Moderate               |

SD = standard deviation; CV = coefficient of variation; ICC = intraclass correlation coefficient; CI = confidence intervals; D = dominant; ND = non-dominant; RFD = rate of force development; s = seconds.

## The Unilateral Isometric Squat

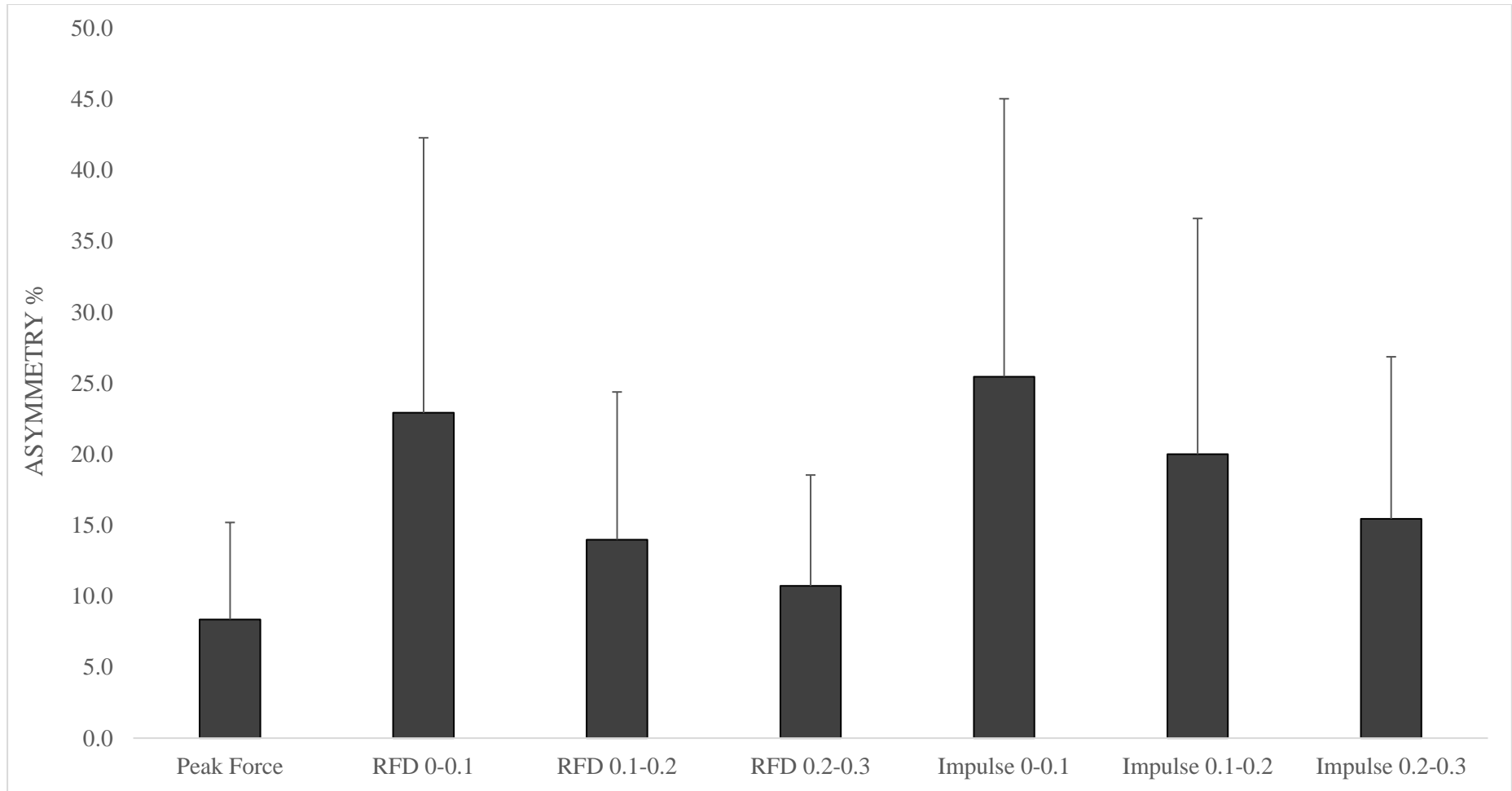


Figure 2: Inter-limb asymmetry values and standard deviations (error bars) for each metric in the unilateral isometric squat test (RFD = rate of force development).

Table 2: Correlations between inter-limb asymmetries and performance on the dominant and non-dominant limbs.

| Asymmetry<br>Variable (%) | Peak Force |                    | RFD      |                    | RFD                |                    | RFD      |                    | Impulse            |                    | Impulse  |                    | Impulse  |                    |
|---------------------------|------------|--------------------|----------|--------------------|--------------------|--------------------|----------|--------------------|--------------------|--------------------|----------|--------------------|----------|--------------------|
|                           |            |                    | 0-0.1    |                    | 0.1-0.2            |                    | 0.2-0.3  |                    | 0-0.1              |                    | 0.1-0.2  |                    | 0.2-0.3  |                    |
|                           | <i>D</i>   | <i>ND</i>          | <i>D</i> | <i>ND</i>          | <i>D</i>           | <i>ND</i>          | <i>D</i> | <i>ND</i>          | <i>D</i>           | <i>ND</i>          | <i>D</i> | <i>ND</i>          | <i>D</i> | <i>ND</i>          |
| Peak Force                | -0.28      | -0.49 <sup>a</sup> | -0.38    | -0.36              | -0.43 <sup>a</sup> | -0.45 <sup>a</sup> | -0.39    | -0.46 <sup>a</sup> | -0.30              | -0.27              | -0.37    | -0.42 <sup>a</sup> | -0.40    | -0.48 <sup>a</sup> |
| RFD 0-0.1                 | 0.08       | 0.02               | -0.17    | -0.57 <sup>b</sup> | -0.17              | -0.34              | -0.06    | -0.16              | -0.24              | -0.54 <sup>a</sup> | -0.19    | -0.52 <sup>a</sup> | -0.19    | -0.40              |
| RFD 0.1-0.2               | 0.01       | -0.08              | -0.38    | -0.56 <sup>b</sup> | -0.27              | -0.52 <sup>a</sup> | -0.21    | -0.32              | -0.47 <sup>a</sup> | -0.61 <sup>b</sup> | -0.37    | -0.59 <sup>b</sup> | -0.32    | -0.54 <sup>a</sup> |
| RFD 0.2-0.3               | -0.21      | -0.31              | -0.41    | -0.50 <sup>a</sup> | -0.38              | -0.47 <sup>a</sup> | -0.27    | -0.50 <sup>a</sup> | -0.43 <sup>a</sup> | -0.41              | -0.40    | -0.47 <sup>a</sup> | -0.40    | -0.48 <sup>a</sup> |
| Impulse 0-0.1             | 0.06       | -0.01              | -0.29    | -0.58 <sup>b</sup> | -0.17              | -0.34              | -0.07    | -0.13              | -0.32              | -0.71 <sup>b</sup> | -0.28    | -0.57 <sup>b</sup> | -0.22    | -0.42 <sup>a</sup> |
| Impulse 0.1-0.2           | 0.01       | -0.10              | -0.20    | -0.54 <sup>a</sup> | -0.20              | -0.40              | -0.13    | -0.22              | -0.25              | -0.55 <sup>b</sup> | -0.22    | -0.59 <sup>b</sup> | -0.21    | -0.49 <sup>a</sup> |
| Impulse 0.2-0.3           | -0.06      | -0.18              | -0.26    | -0.51 <sup>a</sup> | -0.25              | -0.46 <sup>a</sup> | -0.19    | -0.28              | -0.33              | 0.55 <sup>b</sup>  | -0.29    | -0.60 <sup>b</sup> | -0.27    | -0.55 <sup>b</sup> |

<sup>a</sup> = significant at  $p < 0.05$ ; <sup>b</sup> = significant at  $p < 0.01$

RFD = rate of force development; D = dominant; ND = non-dominant

N.B: peak force is measured in Newtons; RFD is measured in Newtons per second; impulse is measured in Newton seconds